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Development of a Detector for Measuring Ejected Debris at the Intermediate Focus of Extreme Ultraviolet Sources

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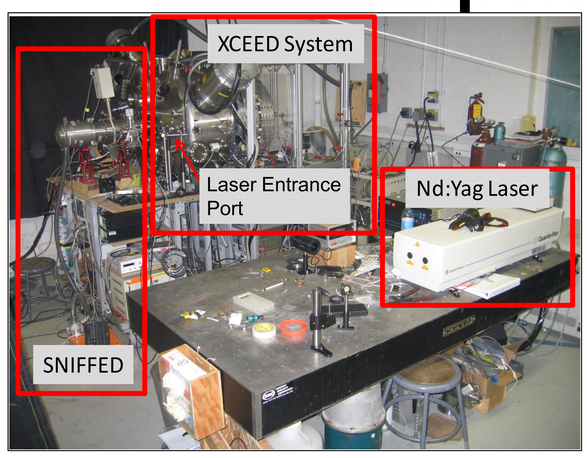
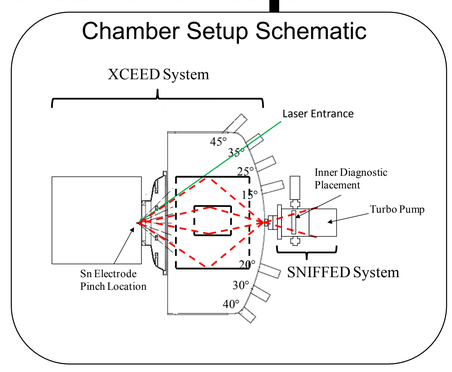
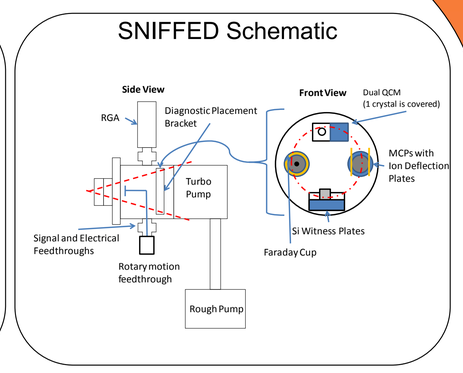
Abstract

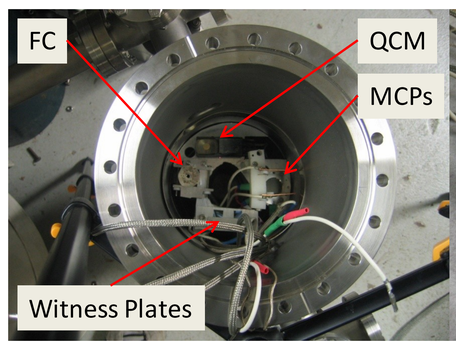
With further progress in extreme ultraviolet (EUV) source debris mitigation techniques, it is now necessary to shift focus to the optical elements downstream of the EUV source. The equipment and materials beyond the intermediate focus (IF) require that only clean EUV photons be transferred across the IF threshold. To evaluate source suppliers' effectiveness in mitigating debris at the IF, the Center for Plasma-Material Interactions (CPMI) at the University of Illinois at Urbana-Champaign has developed a detector capable of characterizing the debris ejected at the IF. The Sn IF flux emission detector (SNIFFED) contains a quartz crystal microbalance (QCM), a residual gas analyzer (RGA), a set of microchannel plates (MCPs) with ion diversion capabilities, a Faraday cup, as well as holders for Si witness plates. These detectors are respectively capable of measuring deposition (or erosion), background gases introduced at the IF, neutral particle flux, charged particle flux, and the method of debris accumulation on any surface located after the IF. CPMI has also developed a simple model to explain the evolution of debris as it progresses from the source to the IF. In this paper, the theoretical results are compared to SNIFFED IF measurements under various conditions.

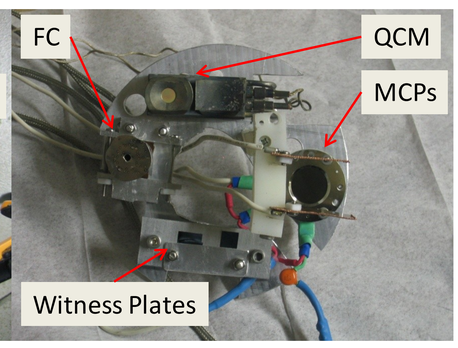
Experimental Setup







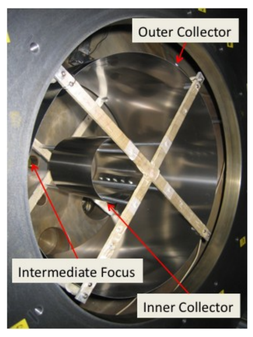


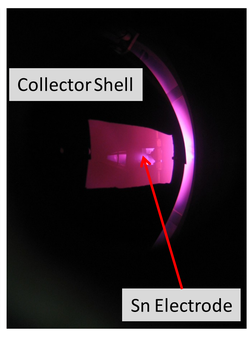


• The Center for Plasma-Material Interactions (CPMI) at the University of Illinois at Urbana-Champaign has an XTREME XTS 13-35. The EUV source has been modified to simulate current Sn-fueled systems with the incorporation of a solid Sn electrode that is laser-ablated with an Nd:YAG laser.

• The modified EUV source is capable of producing 2.3 W in 2π Sr using nitrogen as a pinch gas and a solid Sn electrode.

• CPMI's Nd:YAG laser emits at 1064nm (325mJ), 532nm (125mJ), and 266nm (20mJ) with a frequency of 100 Hz and an average pulse length of 10ns.

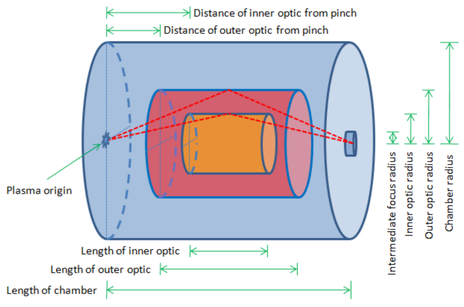




• The Sn Intermediate Focus (IF) Flux Emission Detector (SNIFFED) is composed of a Faraday cup, a quartz crystal microbalance, a set of Si witness plates, a residual gas analyzer, as well as a set of microchannel plates with charged particle diversion in place. The detector is placed at the IF of the chamber to measure emanating flux.

• A set of two mock-up collector optics is installed inside the XTREME Commercial EUV Emission Diagnostic (XCEED) chamber to simulate reflection of debris due to simulated debris transport of a real source-collector module.

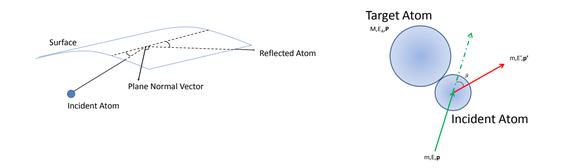
Modeling



• The XCEED chamber was modeled using the approximation that the chamber was comprised of three shells: the outer chamber shell, as well as the inner and outer collector optics.

Simulated Debris Emission

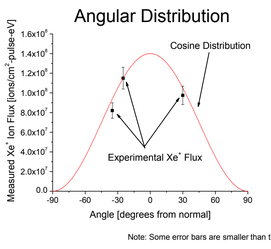
Collisions



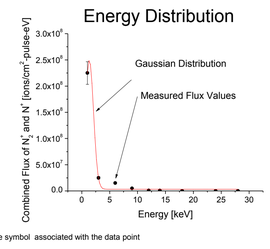
• Collisions are handled with the billiard ball approximation. An energy loss factor is incorporated to determine energy loss at the chamber walls.

• The figure at left shows an example diagram of an atom's trajectory as it progresses from the source (bottom center) to the IF (top center)

Angular Distribution



Energy Distribution

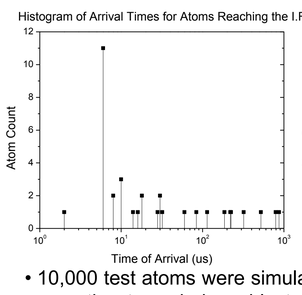


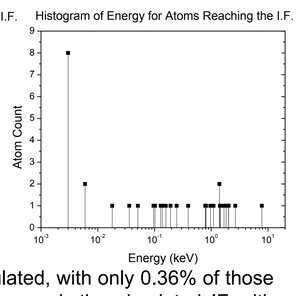
Note: Some error bars are smaller than the symbol associated with the data point

• Modeled atoms are started with an initial energy and angle.

• Using experimental flux measurements of the XCEED system, it was found that the angular distribution of ejected debris was cosine in nature and that the energy distribution of the nitrogen pinch plasma was Gaussian in nature.

Results





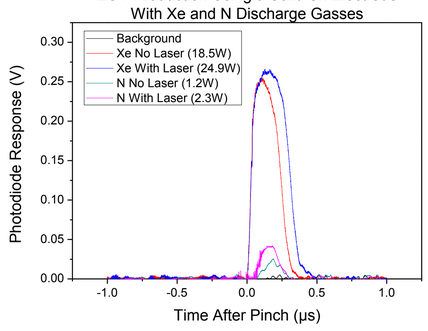
• 10,000 test atoms were simulated, with only 0.36% of those energetic atoms being able to reach the simulated IF with energies above 0.025 eV.

• Of those atoms that made it, it was found that they arrived in an average of 145μs at an average energy of 0.8keV, although a maximum energy of 7.8keV was observed.

• These values are comparable to the flux measurement arrival times observed at the IF with the microchannel plate detectors.

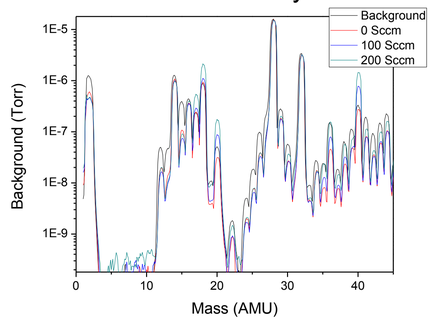
Results

EUV Power Measurements



RGA Analysis

Residual Gas Analysis at IF

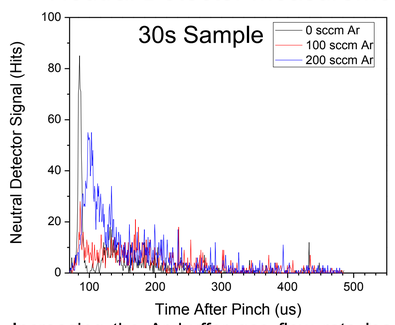


• Increasing the Ar buffer gas flow rate logically increases the partial pressure of Ar observed at the IF.

• Few other changes were observed except for the amount of water at the IF, which increased likely due to contaminated Ar feed lines.

MCP Analysis

Neutral Detector Measurement



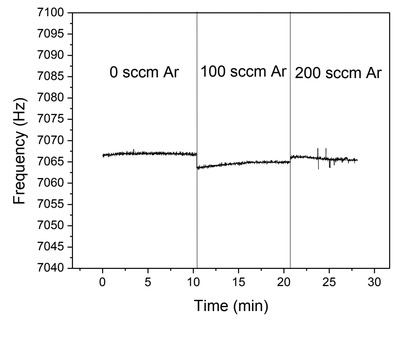
• Increasing the Ar buffer gas flow rate leads to measured flux arriving later (on average) and in larger quantities. Measured values increased from 1392 hits for 0 sccm Ar, to 1640 hits for 100 sccm Ar, and finally to 2907 hits for 200 sccm Ar. Measured average arrival times increased from 147us to 186us and 159us for 0, 100, and 200 sccm Ar respectively.

• Results concurred with Faraday cup measurement results in that no charged flux was observed.

• Time-of-flight would say these are 17eV ions, which cannot be the case since the limit of the MCPs is greater than 0.5 keV

QCM Analysis

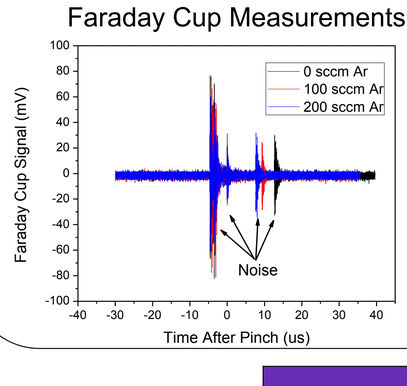
QCM Measurements



• Very little change is observed in the QCM signal during each experiment, suggesting no vast deposition or erosion.

Faraday Cup Analysis

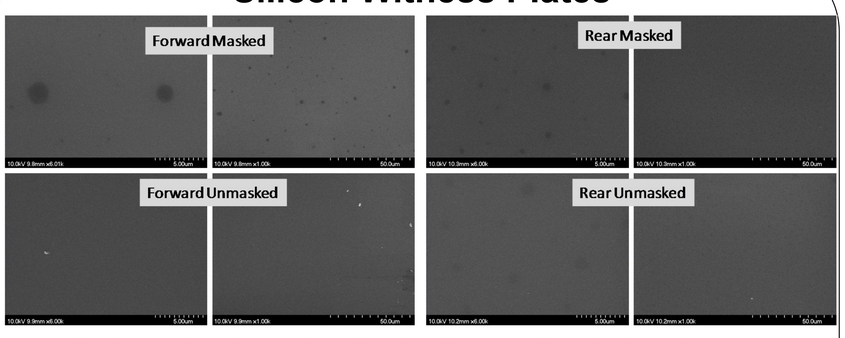
Faraday Cup Measurements



• Varying the Ar buffer gas flow rate did not introduce any observable charged debris into the system.

•All observed signals are from the random noise artifacts present as a result of the discharging of the capacitor banks used in forming the pinch.

Silicon Witness Plates



• No observed erosion or deposition is evident on either the forward- or rear-facing Si witness plates. These plates were in place throughout the 30 minutes of exposure for each of the three experiments.

Conclusion

• CPMI has not only modified the XTREME XTS 13-35 source to mimic current Sn-fueled EUV sources, but has also developed a mock-up collector optic setup that allows CPMI to investigate issues occurring at the intermediate focus of an EUV source.

• The Sn Intermediate Focus Flux Emission Detector (SNIFFED) has been developed to analyze debris exiting the intermediate focus and provide a method by which potential damage to systems down line of the intermediate focus might be damaged.

• Increasing the buffer gas rate from 0 to 400 sccm increases the measured number of hits by 109% from 1392 hits to 2907 hits and increases the average arrival time of each of these measured hits from 147 to 159 us.

• A model has been developed to help analyze what mechanisms are occurring that cause the transportation of highly energetic species to the IF.

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